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CDF and DØ

Jet Production at the Tevatron

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JET PRODUCTION AT THE TEVATRON ¹

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Abstract

Inclusive jet cross section and dijet angular distribution results from the CDF and DØ collaborations are presented. The possibility that compositeness might be evident at high transverse energies is explored by both experiments. Using the angular distributions, the CDF analysis excludes at the 95% CL regions with $\Lambda^+ \leq 1.8$ TeV and $\Lambda^- \leq 1.6$ TeV for a model where all quarks are allowed to be composite objects. The DØ preliminary result excludes at the 95% CL regions with $\Lambda^+ \leq 2.0$ TeV for the same model.

¹for the CDF and DØ collaborations

1 Introduction

Great excitement was generated in 1996 when the CDF collaboration announced an excess of events at large transverse energies (E_T) in the inclusive jet cross section [1, 2]. A deviation from theory in the inclusive jet cross section could indicate the presence of new physics such as new particles or compositeness, or it could be due to a difference in the parton distribution functions (pdf's). The search for compositeness is better performed using the dijet angular distribution, while the search for new particles decaying into jets can be conducted by looking at an invariant mass analysis or a summed E_T (HT) analysis. Differentiation among the various pdf's can be studied through the triple differential cross section.

2 Theory

Theoretical calculations for jet production of order α_s^3 (NLO) have been available for a few years [3, 4]. These calculations include, in addition to the 2-to-2 tree level Feynman diagrams, 2-to-3 tree level diagrams, and 2-to-2 1-loop diagrams. By calculating this next order, it has been possible to reduce the uncertainty due to the renormalization and factorization scales introduced when applying perturbation theory.

For the inclusive jet cross section, the CDF collaboration relies on the EKS [3] program for theoretical predictions, while the DØ collaboration relies on the JETRAD [4] program. Both programs set the renormalization scale equal to the factorization scale, but EKS sets the scale to equal half the E_T of each of the jets in the event, while JETRAD sets the scale to equal half the E_T of the leading jet in the event. This difference was irrelevant at leading order (LO) because both jets must have the same E_T to conserve momentum. The CDF collaboration used the standard Snowmass jet cone clustering algorithm [5] but the DØ collaboration modified the Snowmass algorithm by changing the R_{sep} parameter in the clustering algorithm. R_{sep} is defined as the maximum opening angle that two partons are allowed to have before merging. According to the Snowmass algorithm, the two partons in the same jet can be $2R$ apart, where R is the radius of the cone defined as $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, resulting in $R_{\text{sep}}=2.0$. DØ uses a value of $R_{\text{sep}}=1.3$.

For the dijet angular distribution, both experiments set the choice of scale to be always proportional to the E_T of the leading jet in the event because both use JETRAD. Similar to the inclusive analysis, the DØ collaboration uses a value of $R_{\text{sep}}=1.3$, while the CDF collaboration uses $R_{\text{sep}}=2.0$.

3 Inclusive Jet Cross Section

The inclusive jet cross section analysis counts all the jets in the event that satisfy the pseudo-rapidity [6] and E_T criteria. The cross section is written as

$$\frac{d^2\sigma}{dE_T d\eta} = \frac{N}{\Delta E_T \Delta\eta \int \mathcal{L} dt} \quad (1)$$

and plotted as a function of the jet E_T . N is the number of jets, ΔE_T is the E_T bin size, $\Delta\eta$ is the η bin size, and $\int \mathcal{L} dt$ is the integrated luminosity. The CDF collaboration measures the cross section in the region of $0.1 \leq |\eta| \leq 0.7$, while the DØ collaboration performs the analysis in the $0.0 \leq |\eta| \leq 0.5$ region.

The CDF collaboration has published [1] the results from the 1992-1993 data sample (run 1A) showing an excess compared to theory for E_T above 200 GeV. They implemented EKS with

renormalization scale and factorization scale set at $\mu = E_T^{\text{jet}}/2$ and $R_{\text{sep}}=2.0$. The data from the higher statistics 1994-1995 run (run 1B) also exhibit an excess in the high E_T region. Figure 1 shows the residual plot using EKS with CTEQ3M [7] as the choice of pdf. Also overlayed on the plot are the run 1A data points. The CDF collaboration is in the process of finalizing the systematic error analysis for run 1B and expects the systematic error to be comparable in size to the run 1A analysis.

The largest systematic uncertainty for both experiments comes from the jet energy scale correction. The CDF collaboration has performed a thorough study of their detector including eight different checks for their energy scale correction. The DØ collaboration has reanalyzed their jet energy scale correction resulting in the reduction of the uncertainties at the high E_T region by almost a factor of two. For instance, the uncertainty at $E_T = 70$ GeV is now 2% compared to the previous value of 3% and at $E_T = 400$ GeV the uncertainty is 2.6% compared to the old value of 5%. The size of these uncertainties are comparable to the ones from the CDF collaboration.

The DØ collaboration performs its search in the $0.0 \leq |\eta| \leq 0.5$ region and implements JETRAD with $\mu = E_T^{\text{max}}/2$ and $R_{\text{sep}}=1.3$ where E_T^{max} is defined as the E_T of the leading jet in the event. Figure 2 shows the residual plot using JETRAD with CTEQ3M as the pdf. The data show excellent agreement with NLO QCD prediction and CTEQ3M.

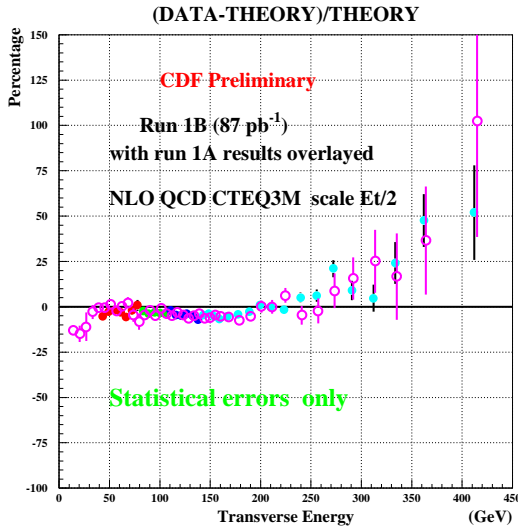


Figure 1: Run 1B residual plot from the CDF collaboration with the run 1A points overlayed. Theory is EKS with CTEQ3M. Errors are statistical only.

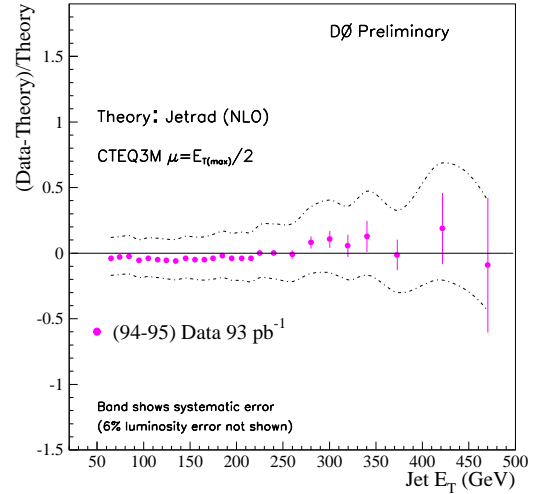


Figure 2: Residual plot of the DØ run 1B inclusive jet cross section compared to JETRAD with CTEQ3M. Error bars are statistical only and the band depicts $\pm 1\sigma$ uncertainty, mainly due to the jet energy scale correction.

Previously, it was not possible to compare the data from the two experiments as they probe different η regions. To facilitate a direct comparison of the data, the DØ experiment has performed the analysis in the $0.1 \leq |\eta| \leq 0.7$ region. These new data have been fitted to a function and used as the baseline in a residual comparison with the CDF data. Figure 3 shows the CDF data points compared to the fit of the DØ data in the $0.1 \leq |\eta| \leq 0.7$ region. The error band corresponds to the DØ systematic uncertainty, which is mainly due to the jet

energy scale correction uncertainties. The CDF data lie above the $D\bar{D}$ fit but within the $D\bar{D}$ uncertainty band.

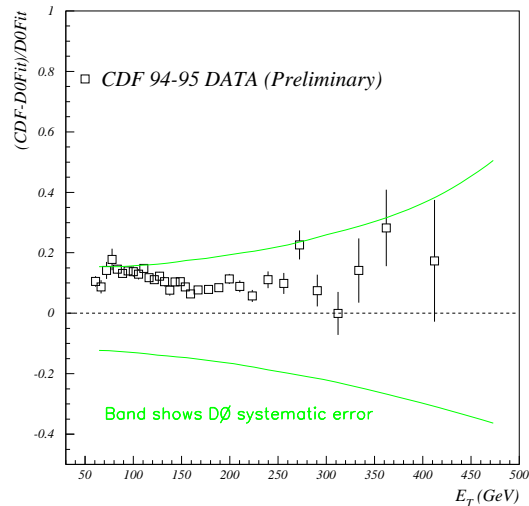


Figure 3: Residual plot of the CDF data with a fit of the $0.1 \leq |\eta| \leq 0.7$ $D\bar{D}$ data. Shown is the systematic band mainly due to the $D\bar{D}$ jet energy scale uncertainty.

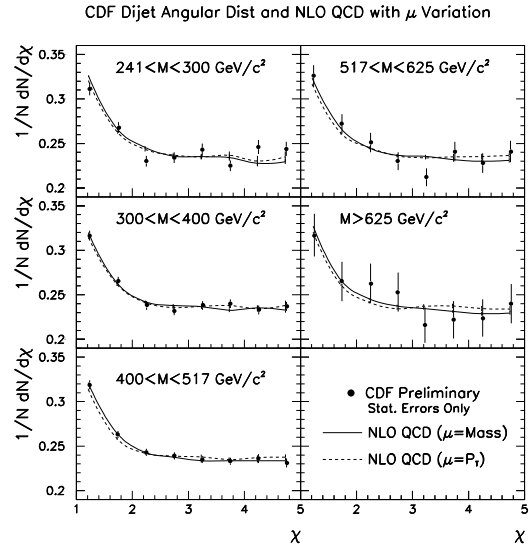


Figure 4: Dijet angular distribution for five different mass bins from the CDF collaboration. The small variation is due to renormalization/factorization scale for $1 \leq \chi \leq 5$. Error bars are statistical only.

4 Dijet Angular Distribution

The dijet angular distribution is an ideal tool to determine whether any observed excess of events might be due to compositeness. Compositeness models are extensions to the Standard model where quarks are allowed to have substructure. One searches for dijet events and plots them as a function of χ , defined as

$$\chi \equiv \exp(|\eta_1 - \eta_2|) = \frac{1 + \cos \theta^*}{1 - \cos \theta^*} \quad (2)$$

for different mass bins, where $\eta_{1,2}$ is the pseudorapidity of the two leading jets and θ^* is the center-of-mass scattering angle. The use of χ flattens the angular distribution, facilitating comparison with theory.

The jets are restricted within the $0.1 \leq |\eta| \leq 2.0$ region and $\chi < 5$ by the CDF collaboration [8]. Figure 4 compares data with theory and demonstrates that very little variation arises due to different scales when looking at regions of $\chi < 5$. To determine a limit, a ratio R is defined as

$$R_\chi = \frac{\# \text{ of events } \chi < 2.5}{\# \text{ of events } \chi > 2.5} \quad (3)$$

for each mass bin. This procedure removes correlations and reduces the curve to a single number. The ratio is then plotted as a function of the mass bin and compared to models with different contact terms. Figure 5 shows the CDF data in excellent agreement with LO and NLO

QCD predictions as well as the behavior of the theoretical predictions when including different contact term values. For a model where all quarks are allowed to be composite objects, the CDF collaboration excludes at the 95% confidence level (CL) regions with $\Lambda^+ \leq 1.8$ TeV and $\Lambda^- \leq 1.6$ TeV.

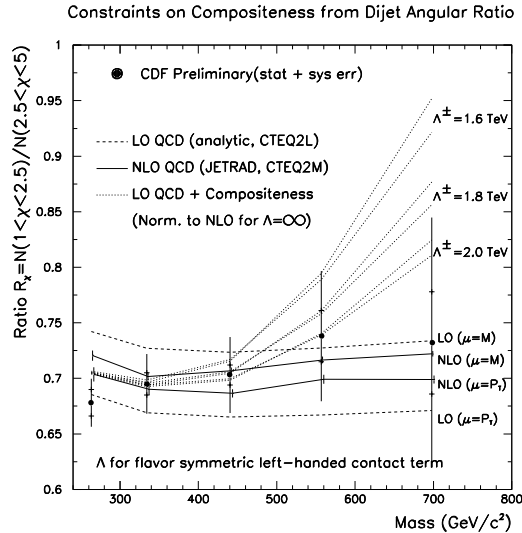


Figure 5: Ratio as a function of the mass bins from the CDF collaboration. Inner error bars are statistical only and outer bars contain statistical and systematic added in quadrature. Data are in excellent agreement with LO and NLO QCD for two different choices of scale. Also shown is the behavior of theory when a contact term is included. Higher ratio corresponds to destructive interference (Λ^+).

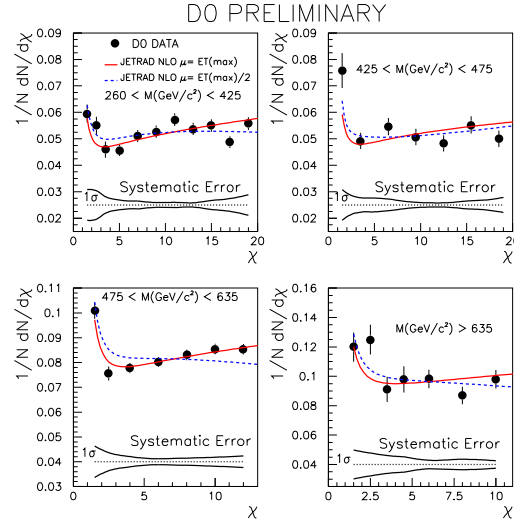


Figure 6: Dijet angular distribution for four different mass bins from the D0 collaboration. Note the large variation due to the renormalization/factorization scale for the wide range of χ . Error bars are statistical only with the systematic error shown separately.

The D0 search is performed for $0.0 \leq |\eta| \leq 3.0$ which includes χ up to 20, when kinematically accessible. Though a large χ range introduces some sensitivity of the theoretical predictions to different renormalization/factorization scale values as shown in Fig. 6, the analysis is more sensitive to higher values of contact term interactions. The D0 experiment also defines a ratio in order to extract a limit. The analysis takes the ratio of the number of events with $\chi < 4$ to the number of events with $\chi > 4$. The D0 experiment rules out a model where all quarks are allowed to be composite objects at the 95% CL regions with $\Lambda^+ \leq 2.2$ TeV when using $\mu = E_T/2$, $\Lambda^+ \leq 2.0$ TeV when using $\mu = E_T$, and $\Lambda^+ \leq 1.9$ TeV when using $\mu = 2E_T$.

5 Conclusions

The CDF collaboration has published their 1992-1993 inclusive jet cross section showing an excess of events for $E_T > 200$ GeV in the region $0.1 \leq |\eta| \leq 0.7$. The excess has been confirmed with the 1994-1995 data sample. The D0 preliminary analysis, however, shows excellent agreement with NLO QCD and modern pdf's (CTEQ3M) in the range $35 \text{ GeV} < E_T < 450 \text{ GeV}$ and in the region $0.0 \leq |\eta| \leq 0.5$. To facilitate a direct comparison between the

two experiments, the DØ collaboration has done the analysis also in the $0.1 \leq |\eta| \leq 0.7$ region. The different conclusions may arise from different choices used in the NLO QCD predictions. Nevertheless, the CDF result is within one sigma of the DØ systematic uncertainties.

The CDF collaboration has published their combined 1992-1993 and 1994-1995 dijet angular distribution analyses excluding, at the 95% CL, regions with $\Lambda^+ \leq 1.8$ TeV and $\Lambda^- \leq 1.6$ TeV for a model where all quarks are allowed to be composite objects. The DØ preliminary result, using a larger χ range, excludes at the 95% CL, regions with $\Lambda^+ \leq 2.0$ TeV for the same model.

Acknowledgments

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